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THE DETERMINISTIC MODELING FOR AVAILABILITY AND SURVIVABILITY EVALUATION OF AVIONICS DISPLAY SYSTEM USING MARKOV MODEL SIMULATION ON MATLAB

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ABSTRACT

This paper targets the deterministic modeling for availability and survivability evaluation of Avionics Display System through simulation on MATLAB using Markov Model. The modern day Glass cockpit are designed to use four Multi Functional Displays (MFDs) to provide information to pilots. This paper presents mainly about Markov modeling through simulation on MATLAB Version 7.7.0 (R2008b) for determining failure rate of MFDs. These MFDs are Line Replaceable Units (LRU). Avionics system's failure rate depends on reliability of 4 LRUs(MFDs) and their failure rates (λ). It is assumed that data is mirrored in all MFDs. With help of Markov Model on MATLAB, graphical analysis of failure rate over a period of long time can be simulated. "Analysis of Failure rate of Multi Function Display (MFD)" concludes that Failure Rate of the system works out to be 84.885 Failures / 10^6 Hrs.

KEYWORDS: Avionics Display, Markov Model, MATLAB, Availability & Survivability

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Original Article

1. INTRODUCTION

1.1 BACKGROUND

Avionics design are aimed for multirole missions and offer vast range of functionalities required for support during operations to reduce the workload of the crew and increasing performance of the machine. Avionics provide crews with an array of capabilities. Cockpit crews can operate with two pilots, greater efficiency, and with immediate critical information. Since avionics are one of the most expensive items on an aircraft, designers are continually challenged to produce cost-effective, highly reliable system. Growing technological advancements have resulted in information overflow in the cockpit. The display system provides the much needed information in the form which can be easily assimilated into an overall awareness of the current situation in and around, raising the need of a reliable system.

1.2 Survivability

It is traditionally defined in military systems as a capability of a system to avoid orwithstand a hostile environment. It can be enhanced by reducing both susceptibility and vulnerability. It is the ability of a system to minimize the impact of a finite disturbance or value delivery [1].

1.3 Reliability

It is the probability of a system that it will deliver the intended service satisfactorily at time t when used under defined specific conditions. Reliability prediction is used to identify failure prone areas i.e. weakness of design and areas requiring redundancy[2][3].

1.4 Availability

It is function of time defined as the probability that a system is operating correctly in its intended use and is available to perform its function at the instant time tof a mission. The mission could be the 18-hour span of an aircraft flight. The mission period could also be the 3 to 15-month span of a military deployment. Availability includes non-operational periods associated with reliability, maintenance, and logistics[3][4].

In the dependability analysis of repairable computing systems, there is an interest in evaluating cumulative measures, in particular, the availability over a given period. Considering, for instance, critical applications, it is crucial for the user to ensure that the probability that its system will achieve a given availability level is high enough [5].

1.5 Cockpit Architecture for Displays

The cockpit architecture having four Multi Function Displays having capability of all the requisite data to be displayed to achieve a particular mission isshown in Figure.1.

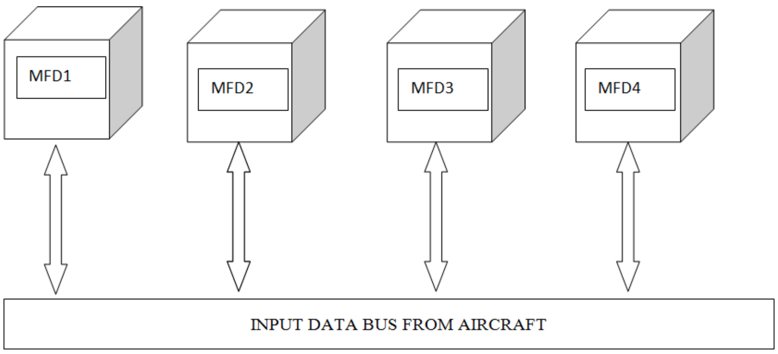

Figure 1: Cockpit Architecture

1.6 Markov Model

Reliability of complex systems often is described by the homogeneous Markov process [6]. Markov Model consists of a list of all possible states of that system, the possible transition paths between those states and rate parameters of those transitions. Markov model is a study of an important new type of chance process. In this process, the outcome of a given experiment can affect the outcome of the next experiment. This type of process is called a Markov chain.

Major benefits derived from a properly implemented Markov model are as follows:

- It can visualize a finite state machine.
- It has strong statistical foundation, efficient learning algorithm. Learning can take place directly from raw sequence.
- It can handle inputs of variable length and time variation.

- It may be used in wide variety of application including multiple alignment, data mining & classification & structural analysis.

Semi-Markov or Markov renewal processes are commonly used tools for the study of reliability and perfected characteristics of technical systems[7]. When representing Markov Model graphically, each state is usually depicted as a 'Bubble', with arrow denoting the transition paths between states, as shown in Figure.2 for a single component that has just two states: Healthy & Failed [8].

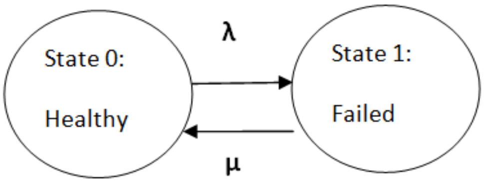

Figure 2: Basic Markov Model [8]

Where,

λ denotes the rate parameter(failure rate) of the transition from state 0 to state 1.

μ denotes repair rate of the transition from state 1 to state 0.

Similarly Pj(t) denotes the probability of the system being in state j at time t.

A Markov chain is described as set of states,

S = (S1; S2; ----- ; Sr)

The process starts in one of these states and moves successively from one state to another. Each move is called a step. If the chain is currently in state Si, then it moves to state Sj at the next step with a probability denoted by Pij, and this probability does not depend upon which states the chain was in before the current state. The probabilities Pij are called transition probabilities.

The state equations for state k sets denote probability flows corresponding to each of transitions into and out of that state. It must possess a property called "Markov property" which says that the probability distribution of the next state, given states up to now, depends only on the current state and not on the sequence of events that preceded it. The time parameter is usually discrete and, mostly, all applications in Markov Chains employed finite or countable infinite state spaces, which have a more straightforward statistical analysis. Since the system changes stochastically, it is almost impossible to predict with certainty the state of a Markov Chain at a given point in the future. However, the future system statistical properties can be predicted and, in many cases, are these statistical properties which are important

2. ANALYSIS THROUGH MARKOV MODEL OF 4 UNIT (MFD) SYSTEM

In analysis of 4 MFDs model, it is assumed each state have repair rates μ_0, μ_1, μ_2& μ_3 as well as failure rates λ_0, λ_1, λ_2, λ_3& λ_4. Each state should have its own state probability i.e.: P_0, P_1, P_2, P_3& P_4. The transition state Markov Model for this case is shown in Figure.3[9],[10]:

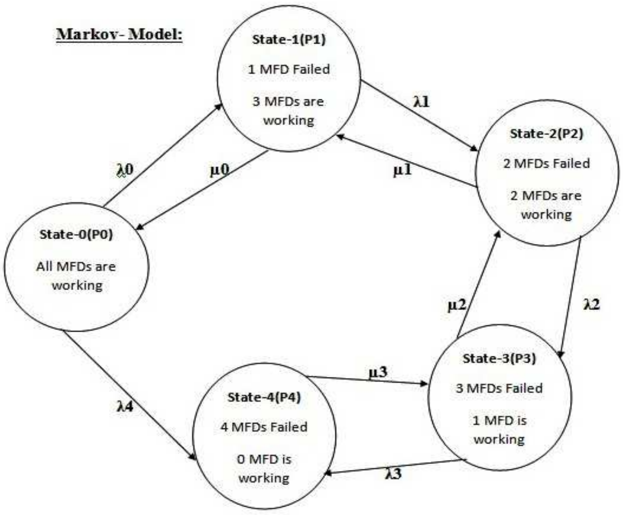

Figure 3: 4 MFDs Transition State Markov Model

Total Probability Input to a State = Total Probability Output from that State

State-0 Equation

Incoming flow of state 0 = Outgoing flow of state 0

$$\mu_o P_1 = (\lambda_o + \lambda_4)P_o$$

$$(\lambda_0 + \lambda_4)P_0 - \mu_0 P_1 = 0 \quad (1)$$

State-1 Equation

Incoming flow of state -1 = Outgoing flow of state -1

$$\lambda_0 P_0 + \mu_1 P_2 = \mu_0 P_1 + \lambda_1 P_1$$

$$\lambda_0 P_0 - (\lambda_1 + \mu_0) P_1 + \mu_1 P_2 = 0 \quad (2)$$

State-2 Equation

Incoming flow of state -2 = Outgoing flow of state -2

$$\lambda_1 P_1 + \mu_2 P_3 = \lambda_2 P_2 + \mu_1 P_2$$

$$\lambda_1 P_1 - (\lambda_2 + \mu_1) P_2 + \mu_2 P_3 = 0 \quad (3)$$

State-3 Equation

Incoming flow of state -3 = Outgoing flow of state -3

$$\lambda_2 P_2 + \mu_3 P_4 = \lambda_3 P_3 + \mu_2 P_3$$

$$\lambda_2 P_2 - (\lambda_3 + \mu_2) P_3 + \mu_3 P_4 = 0 \quad (4)$$

State-4 Equation

Incoming flow of state -4 = Outgoing flow of state -4

$$\lambda_3 P_3 + \lambda_4 P_0 = \mu_3 P_4 \tag{5}$$

Since repair rate of fully-failed state (state-4) is infinite, probability of that state P_4 will be zero.

Now the total system failure rate is the total flow-rate into that state, hence

$$\lambda_{SYSTEM} = \lambda_3 P_3 + \lambda_4 P_0 \tag{6}$$

2.1. Matrix Notation of Markov Model

In general there is a state equation for each state of the model, but these equations are not all independent, because the sum of all the state probabilities must always equal 1. Conversions of above equations from (1) to (4) can be converted in Matrix form:

$$(\lambda_0 + \lambda_4) P_0 - \mu_0 P_1 = 0$$

$$\lambda_0 P_0 - (\lambda_1 + \mu_0) P_1 + \mu_1 P_2 = 0$$

$$\lambda_1 P_1 - (\lambda_2 + \mu_1) P_2 + \mu_2 P_3 = 0$$

$$\lambda_2 P_2 - (\lambda_3 + \mu_2) P_3 + \mu_3 P_4 = 0$$

It is convenient to replace the first equation with the conservation requirement

$$P_0 + P_1 + P_2 + P_3 + P_4 = 1 \tag{7}$$

The resulting set of equations is solvable and can be written in matrix form as:[2]

C P = U

$$P = \begin{bmatrix} P0 \\ P1 \\ P2 \\ P3 \\ P4 \end{bmatrix} \qquad U = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ (\lambda 0+\lambda 4) & -\mu 0 & 0 & 0 & 0 \\ \lambda 0 & -(\lambda 1+\mu 0) & \mu 1 & 0 & 0 \\ 0 & \lambda 1 & -(\lambda 2+\mu 1) & \mu 2 & 0 \\ 0 & 0 & \lambda 2 & -(\lambda 3+\mu 2) & \mu 3 \end{bmatrix}$$

The solution is simply $\mathbf{P} = \mathbf{C}^{-1}\mathbf{U}$**.** In general system shutdown rate will be some linear combination of the state probabilities. In this example, the system shutdown rate is λ3P3 + λ4P0**.** We can define Row vector **L = [λ4 0 0 λ3 0].**

The average system failure rate

$$\boldsymbol{\lambda_{system}} = \mathbf{L} \times \mathbf{P} = \mathbf{L} \times \mathbf{C}^{-1}\mathbf{U} \tag{8}$$

2.2. Experimental Results on Matlab

During simulation of above matrix through MATLAB Version 7.7.0 (R2008b), different kind of functions of Matrix &Markov model has been used. In Simulator, all repair rates and failure rates have been fed and analyses has been carried out. Repair rate is assumed to be once in 6 months and failure rate to be equal to 333.3 failures per 10^6 Hrs for each Multi Function Display (MFD). Final average system failure rate generated by MATLAB is8.4885× 10^{-5}Failures(84.885 failures per 1000000 hrs) as shown in Figure.4.

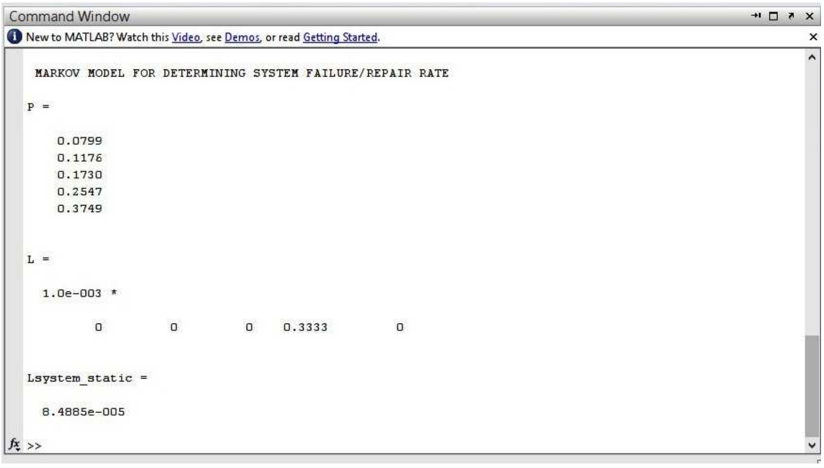

Figure 4: System Failure Rate shown in Command Window in MATLAB for Markov Model

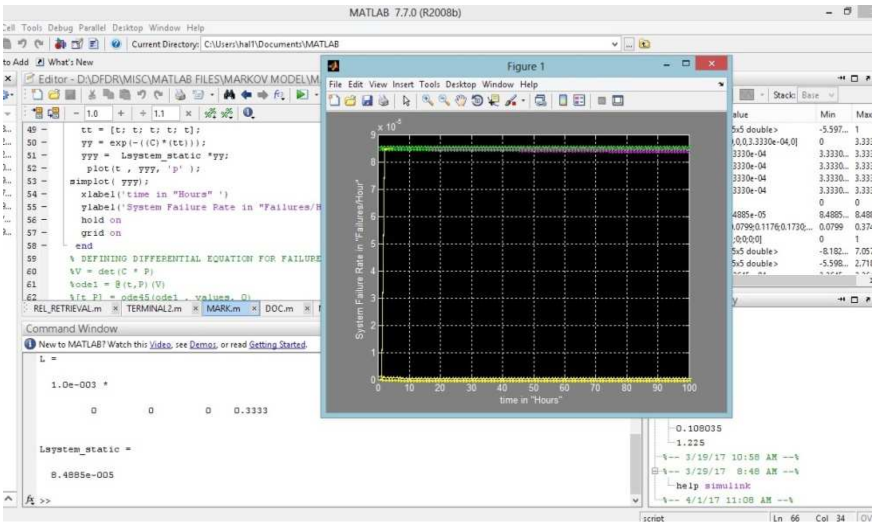

Figure 5: Transient Response of System Failure Rate Shown in MATLAB for Markov Model

It is reflecting in Figure. 5 that the instantaneous rate has already come close to steady state rate (λ_{system} of Matrix notation form) in 10 hours of operations. Typically an entire fleet will operate for thousands of hours, so the transient behavior during first several hours is insignificant. This is why the steady-state analysis (matrix notation as per section 2.1) is usually adequate for determining the average system failure rate of the closed-loop system.

3. CONCLUSIONS

The paper describes a specific computational approach to reliability analysis of 04 MFDs Cockpit architecture systems, which behavior is described by the Markov chain finite-state transition diagram.

An examination of the analyses using markov model simulation on MATLAB shows that for an architecture of 04 MFDs being used in a cockpit will have an system failure rate of 84.885×10^{-6} Failures per hour. It shows availability of system for aircraft use is quite high and system will survive for its intended use.

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